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Comparison of Collembolan populations structure from Portuguese forests of *Pinus pinaster* AITON and *Eucalyptus globulus* LABILL.

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ABSTRACT. The authors studied the effects of reafforestation by *Eucalyptus globulus* LABILL. on the edaphic collembolan populations occurring in coppices of *Pinus pinaster* AITON and stands of *E. globulus* in Sever do Vouga, central Portugal.

This study, using both diversity and similarity measures, revealed that, among a total of 5132 specimens distributed in 58 taxa, the original forest has the less abundant but the richest and most diverse *Collembola* populations of both sites, with only 935 individuals but 46 taxa, 17 of them revealing exclusivity. In opposition, eucalyptus has 4197 specimens but only 41 taxa, 12 of them exclusive to this site.

Despite this difference, 50% of the species are common to both sites and thus no distinct separation between them nor any clear faunal stratification between organic and mineral horizons could be found.

These findings can be attributed to the fact that eucalyptus plantation does not follow the usual exploitation procedures, resulting in an enrichment of soil due to a great accumulation of organic debris. In fact all litter physical and chemical parameters have higher values for eucalyptus site, compared with pine wood.

INTRODUCTION

The study presented in this paper is a part of STEP-CE's research project entitled "Fluctuation of Biodiversity patterns following reafforestation with indigenous versus exotic tree species". Its aim is to evaluate the relationships between the edaphic fauna of *Collembola* from *Pinus pinaster* AITON forest and the fluctuations in diversity induced by the reafforestation with *Eucalyptus globulus* LABILL.

The massive plantation of eucalyptus in Portugal has been subjected to a great controversy between the ecologists and economists. The species, native of Australia and Tasmania, was introduced in our country 150 years ago, exclusively for ornamental purposes. In 1926 it was first used in the production of cellulose paste. However, it was only since the 60's that eucalyptus plantations have been expanded, to an extension of 539,000 hectares in our days. This expansion has been encouraged by cellulose industries.

The area planted with *Pinus pinaster*, the main species replaced by eucalyptus, reached 1,457,000 hectares in 1978, and in recent years has fallen to only 1,050,000 hectares. The eucalyptus has also occupied partially the place of the dominant original *Quercus* forests: *Q. robur* L. and *Q. pyrenaica* WILLD. in the northern part of the country and *Q. ilex ballota* (DESF.) SAMP. (= *Q. rotundifolia*) and *Q. suber* L. in the central and southern regions.

Our research, concerning the evaluation of the impact of eucalyptus stands on the edaphic *Collembola* fauna (FIGUEIREDO et al. 1985, GAMA et al., 1989, 1991, 1994, SOUSA and GAMA 1994, VASCONCELOS et al. 1994), has revealed that natural forests (*P. pinaster*, *Q. suber* and *Q. ilex ballota*) show a higher diversity and species richness than eucalyptus plantations, which also are, in general, poorer in exclusive and preferential species. Our present study confirms these results in a general way.

MATERIALS AND METHODS

STUDY SITES

The sampling stations were located in Sever do Vouga, district of Aveiro, central littoral region of Portugal. Situated at an average altitude of 300m, *Pinus pinaster* and *Eucalyptus globulus* stands were contiguous and on both sites trees were planted in 1977 after a forest fire (in 1973). Before the fire the entire area was covered with pine wood. On both sites trees were planted in grooves following the altitude lines, which leaded to an accumulation of leaf litter.

According to physical and chemical data (Table 1) both sites were not statistically different, except for litter thickness, litter water content and soil temperature. This similarity in terms of pedological data can be attributed to a reduced anthropogenic influence on the area, leading to the development of substantial herbaceous (mainly *Pteridium aquilinum* and shrub (*Ulex europaeus* L., *Erica* sp., *Calluna vulgaris* and *Chamaespartum tridentatum* (L.) GIBBS) layers, particularly in the eucalyptus stand. Twelve years after the plantation, the eucalyptus trees were felled, and all the area was kept untouched with a new set of trees and shrub vegetation growing freely. The wood and bark remnants were left in place, contributing to an increase in standing stock biomass and in organic horizon thickness.

The soil is a typical cambisoil resulting from schist rocks sometimes associated with humic soils (specially in the lower regions) and the climate of the area is mesothermic and super-humid, leading to a very low water deficiency.

Table 1

Geographical, physical and chemical characterization of study sites (range or mean ±SD). For physical and chemical analysis, samples were cumulated and means were compared by t-test

	P.pinaster	*E. globulus*	
Slope	2% — 15%	15% — 17%	
Exposition	N120°E - N165°E	N135°E - N235°E	
Litter thickness (cm)	1,1±0.01	1.7±0.63	*
Soil pH	4.72±0.37	4.48±0.50	n.s.
Soil temperature (°C)	12.6±1.3	14.8±1.2	*
% Water content (litter)	27.52±11.09	38.36±16.69	**
% Water content (soil)	24.23±6.63	25.85±5.91	n.s.
% Carbon (soil)	7.61±2.89	8.64±2.72	n.s.
% Nitrogen (soil)	0.33±0.13	0.34±0.13	n.s.
C/N (soil)	24.04±2.76	26.97±7.45	n.s.
% Org. matter (litter)	53.75±16.85	56.75±13,1	n.s.
% Org. matter (soil)	12.51±4.99	14.37±5.45	n.s.

* $p<0.001$ ** $p<0.05$ n.s. - non significant

SAMPLING, SOIL CHARACTERISATION AND FAUNA EXTRACTION

Sampling was done in March 1992. At each stand 4 randomly selected quadrats (8m per 8m) were divided in 16 small squares (2m per 2m). Inside each plot, 4 squares were also randomly selected, making a total of 16 sampling squares per site. After a careful removal of the undecomposed leaf layer, one sample in the organic horizon (litter) and another in the mineral horizon (soil) were taken at each square. Simultaneously, soil temperature (at the depth of 10 cm) and organic horizon thickness were measured. To catch epigeic fauna, a pitfall trap (a plastic vial of 2 cm of diameter) was placed at each sampling square for one week.

Fauna was extracted by means of BERLESE-TULLGREN funnels, sorted under stereo microscope and identified to species level under light microscope. Water content was expressed as percentage of water in relation to dry weight at 105°C. Organic matter content was expressed on an "Ash Free Dry Weight" basis and carbon and nitrogen content were measured with ANNE'S and KJELDAHL'S methods respectively (DEWIS, FREITAS 1984). pH was measured in water (1:6 v/v) at 20°C.

DATA ANALYSIS

Comparisons of community composition between both sites were made using both diversity and similarity measures. In the first analytical approach, species diversity, evenness and species richness were calculated for the different strata inside each site (samples were cumulated for each stratum), following SHANNON-WEAVER, PIELOU and MARGALEF indices, respectively (MAGURRAN 1991).

For the second group of analyses, the BRAY-CURTIS coefficient was selected because of its reported robustness in analysing ecological data (FAITH et al. 1987). Similarity was measured among and between samples from the two sites. Prior to the analysis, raw data were transformed to $y_{ij}=\mathrm{Log}(x_{ij} + 1)$. Two types of analytical procedures were performed using this coefficient:

– The first procedure was carried out to associate statistical power with a comparative analysis between both communities. In this case the average similarity among pine wood samples at each stratum ('control' group) was tested against the corresponding average similarity of the 'treatment' group (pine wood vs eucalyptus samples) by means of a t-test. For this analysis, data inside each plot were cumulated, making a total of 4 experimental units per site. To achieve homoscedasticity of sample variances, an arcsin transformation was performed in the similarity data before the t-test comparison.

– The second analytical procedure was done to visualize the relations among the different strata and among taxa. In this case, an agglomerative hierarchical clustering method was applied to the two similarity matrices resulting from the BRAY-CURTIS resemblance measure (normal and inverse analysis). In this case data from the total number of samples at each stratum were pooled, making a raw matrix of 6 groups for 58 taxa. As a way to enhance the interpretation of results from the numerical classification, a post-clustering 'nodal analysis' (BOESCH

1977) was performed. This procedure relates normal to inverse analysis where groups of similar samples are related to groups of co-occurrence taxa. This is done using the ecological concepts of constancy and fidelity. Both were graded according to BOESCH (1977) and numerically expressed as:

- $C_{ij} = a_{ij}/(n_i n_j)$ for Constancy
- $F_{ij} = (a_{ij} \Sigma n_j)/(n_j \Sigma a_{ij})$ for Fidelity

where **aij** is the actual number of occurrences of members of species group **i** in the samples group **j** and the **ni** and **nj** are the numbers of entities in the respective groups. Constancy index has a maximum of 1 when all species occurred in all samples in the group and a minimum of 0 when none of the species occurred in that particular samples group. Fidelity values greater than 2 suggest strong 'preference' of species in a group for a samples group and values lower than 1 suggest 'avoidance' of the spatial habitat represented by the samples group or negative fidelity.

RESULTS

A total of 5132 specimens, distributed in 58 taxa, were identified. *Pinus pinaster* supports the less abundant but the richest and most diverse collembolan populations of both sites, with only 935 specimens but 46 taxa. In opposition, *Eucalyptus globulus* populations have 4197 specimens and only 41 taxa (Table 2).

The autochthonous forest shows higher values of species diversity in litter and pitfall trap samples (Table 2) than the allochthonous stand. In contrast, the species diversity in soil has higher values in eucalyptus stand. The difference in diversity values of litter and soil can be explained not by the difference in number of taxa on both stands (considering a comparison at each horizon), but by the distinct evenness values found there, with lower values being connected with high abundance of a few species. The lower diversity in soil of pine wood is therefore related to a high number of specimens of *Tetracanthella hygropetrica* and the decrease in diversity in eucalyptus litter is related to a high abundance of *Xenylla franzi* and also *T. hygropetrica*. On the contrary, at pitfall trap samples, the lower diversity in eucalyptus stands is explained by the lower number of species and not by the evenness (Table 2).

Species richness values are higher in pine wood than in the eucalyptus stands both in soil, litter and pitfall trap samples. Once more, this is related not with the number of taxa, but with a lower number of individuals in the autochthonous site.

Table 2

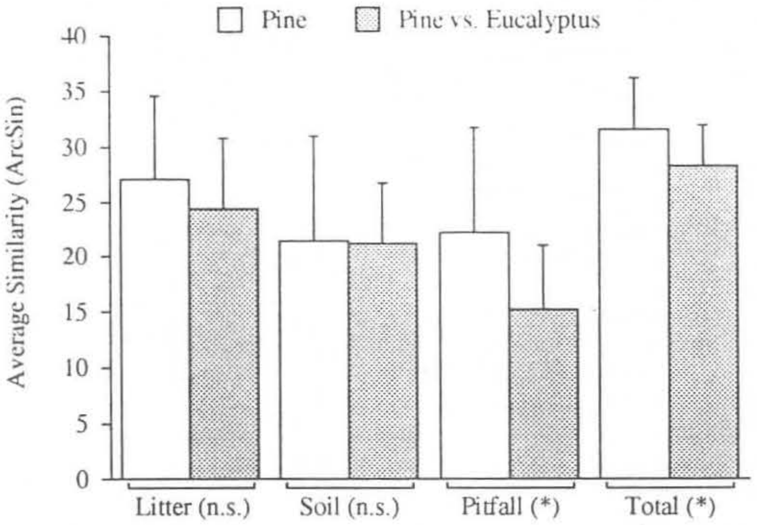
Total number of individuals of Collembolan species in coppices of pine wood and eucalyptus plantations, diversity, evenness and species richness for different strata on both sites

Taxa	*Pinus pinaster*			*Eucalyptus globulus*		
	Soil	Litter	Pitfall	Soil	Litter	Pitfall
Acherontiella xenylliformis (GISIN, 1951)					1	
Ceratophysella engadinensis (GISIN, 1951)					1	
Ceratophysella gibbosa (BAGNALLI, 1940)				17	17	
Microgastrura duodecimoculata STACH, 1922	1					
Xenylla franzi STEINER, 1955	1	23	1	33	1292	6
Xenylla schillei BÖRNER, 1903		7	4	1	3	
Anurida sp. (0+0 eyes)	4					
Bilobella aurantiaca (CAROLI, 1912)	1	4		5	44	
Deutonura portucalensis (GAMA, 1964)	1			1	3	
Friesea mirabilis (TULLBERG, 1871)	7					
Micranurida sp. (2+2 eyes)	4	18		35	62	
Pseudachorutella asigillata (BÖRNER, 1901)					2	
Pseudachorutes palmiensis BÖRNER, 1903		1				
Pseudachorutes subcrassus TULLBERG, 1871	1	1			15	1
Rusekella gamae ARBEA e JORDANA, 1991	1	3		1	24	
Superodontella carmenae ARBEA/LUCIANEZ, 1991				1	1	
Mesaphorura arbeai SIMON/LUCIANEZ	3	2		7	5	
Mesaphorura coimbrensis SIMON/LUCIANEZ	2	3		7	11	
Mesaphorura isochaeta ARBEA/JORDANA, 1989				1		
Mesaphorura macrochaeta RUSEK, 1976	20	3		15		
Mesaphorura yosii (RUSEK, 1967)	3	2		7		
Mesaphorura sp.	2	2			2	
Onychiurus circulans GISIN, 1952	3	1		5		
Paratullbergia callipygos (BÖRNER, 1902)	1			20		
Protaphorura armata (TULLBERG, 1869)				11	13	
Cryptopygus scapelliferus (GISIN, 1955)		3				
Cryptopygus thermophilus (AXELSON, 1900)	6					
Folsomia sexoculata (TULLBERG, 1871)	14					
Isotomiella minor (SCHÄFFER, 1896)				1		
Isotomurus fucicola (REUTER, 1891)	4	5			1	
Isotomurus palustris aquatilis (MÜLLER, 1776)	3					
Parisotoma notabilis (SCHÄFFER, 1896)				1		
Proctostephanus madeirensis GAMA, 1959				21	9	
Proisotoma coeca GAMA, 1961	1					
Tetracanthella hygropetrica CASSAGNAU, 1954	245	99		183	1526	1
Tetracanthella proxima STEINER, 1955	2	14				
Entomobrya cf. *muscorum* (NICOLET, 1841)	5	32	7	4	25	
Entomobrya multifasciata (TULLBERG, 1871)		41	2	2	22	6
Entomobrya pazaristei DENIS, 1936			1			
Heteromurus major (MONIEZ, 1889)	2	33	8	26	214	10
Lepidocyrtus lusitanicus GAMA, 1964				2	43	3
Lepidocyrtus paradoxus UZEL, 1890		7	1	3	6	6
Lepidocyrtus sp.	5	46	22	6	37	8

Pseudosinella infrequens GISIN/GAMA, 1969	1	4			2	
Pseudosinella picta (BÖRNER, 1903)	3	2		11	148	
Sinella sp. (4+4 eyes)		1		4		
Entomobryidae juv.	19	125	2	85	44	8
Cyphoderus albinus NICOLET, 1842					3	
Pogonognathellus flavescens (TULLBERG, 1871)		6	2			
Tomocerus vulgaris (TULLBERG, 1871)		1	3	2	11	1
Megalothorax minimus WILLEM, 1900		4				
Arrhopalites sericus GISIN, 1947	3				4	
Bourletiella sp.	3	3	5	3	3	31
Caprainea bremondi (DELAMARE/BASSOT, 1957)		2	1			
Dicyrtomina minuta (FABRICIUS, 1783)			2			
Sminthurides parvulus (KRAUSBAUER, 1898)			1			
Sminthurinus bimaculatus (AXELSON, 1902)		2				
Sminthuridae juv.		2		1		
Number of individuals	**371**	**502**	**62**	**522**	**3594**	**81**
Number of Taxa	**31**	**33**	**15**	**32**	**32**	**11**
Shannon index (H')	**2.37**	**3.62**	**3.15**	**3.47**	**2.31**	**2.81**
Evenness (E)	**0.48**	**0.72**	**0.81**	**0.69**	**0.46**	**0.81**
Margalef index (D)	**5.07**	**5.15**	**3.39**	**4.95**	**3.79**	**2.28**

Considering similarity data and comparing the average similarity among pine wood site (control) and the average similarity between pine wood and eucalyptus stands (treatment) (Fig. 1), there are no significant differences in litter and soil horizons values. The opposite occurs in the pitfall trap samples and considering all the strata as a whole. Although this graph requires a careful interpretation, it may reflect some of the true essence of data, without balancing of the diversity and/or richness gradients.

The phenogram of Q mode analysis shows that the organic horizon of pine wood is more related with the two strata of eucalyptus than with the correspondent soil horizon (Fig. 2). This may be explained by the presence of some species of group C [*Rusekella gamae*, *Bilobella aurantiaca* and *Micranurida* (2+2 eyes)] and specially of group D (*Xenylla franzi*, *Heteromurus major*, *Entomobryidae* juv., *Entomobrya* cf. *muscorum*, *Lepidocyrtus* sp.) which are more abundant in litter and soil of eucalyptus and pine wood litter than in mineral horizon of *P. pinaster*. Pitfall traps are grouped together and are separated from the corresponding sites. This must be related with the presence of eight taxa of group D in pitfall trap samples of both sites (*Xenylla franzi*, *Heteromurus major*, *Entomobryidae* juv., *Lepidocyrtus* sp., *Entomobrya multifasciata*, *Lepidocyrtus paradoxus*, *Tomocerus vulgaris* and *Bourletiella* sp.)



1. Average similarities (±SD) on control (pine wood) and treatment (pine wood vs eucalyptus) groups for the different strata. Groups were compared by a t-test: * $p<0.05$; **n.s.** non-significant

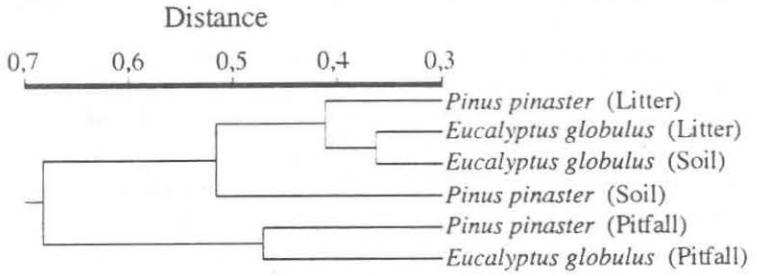
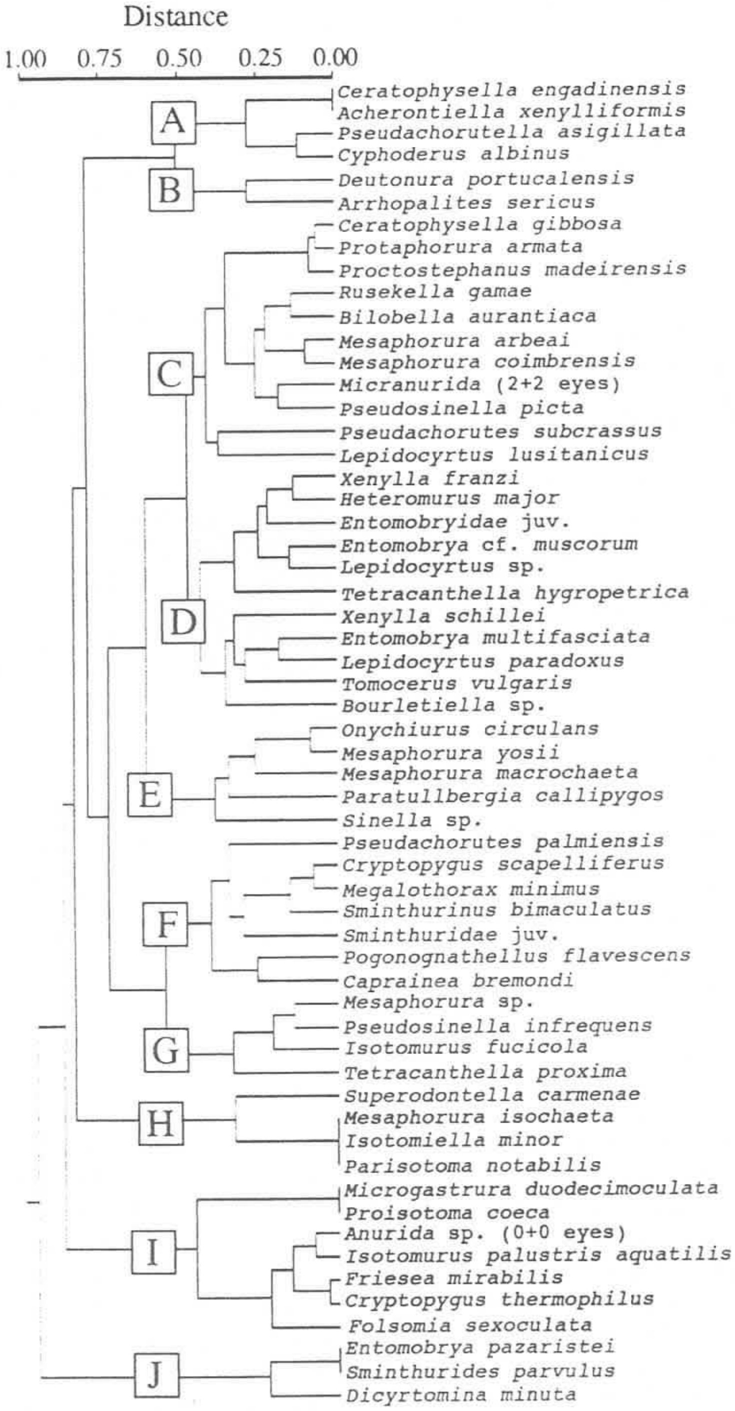


Fig.2 - Phenogram corresponding to the Q mode analysis based on Bray-Curtis distance.

2. Phenogram corresponding to the Q mode analysis based on BRAY-CURTIS distance

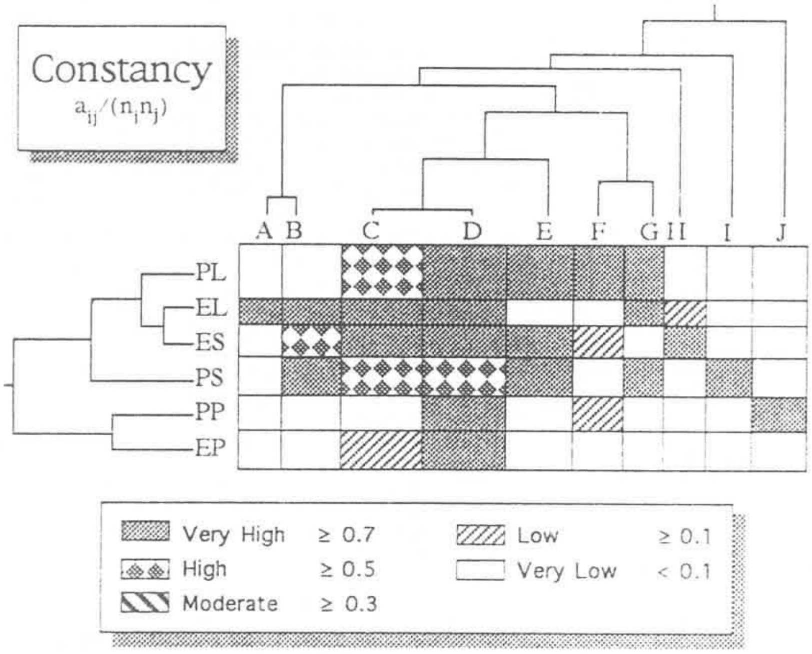
In the phenogram on the R mode analysis (Fig. 3), 10 groups of taxa can be distinguished. Only two (groups A and H) are composed of species showing an exclusive preference for eucalyptus, either in the organic (group A) or mineral horizon (H group, except *Superodontella carmenae* which is also present in litter – cf. also Figs 4, 5).

Also two groups, I and J, present exclusivity in pine wood site, showing very high values of constancy and fidelity for mineral horizon and pitfall trap samples respectively (Figs 4, 5). Taxa of group F (except *Sminthuridae* juv.) are also exclusive of pine wood, occurring preferentially in litter.



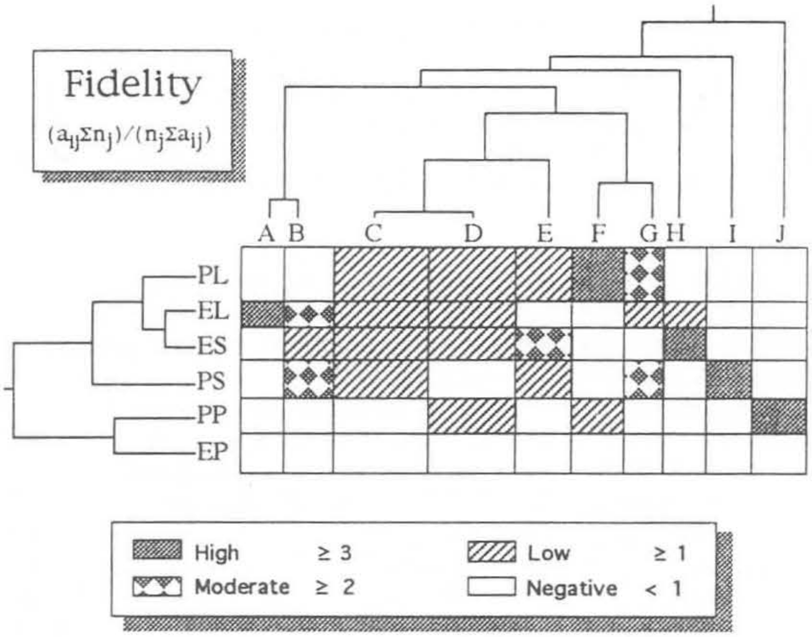
3. Phenogram corresponding to the R mode analysis based on BRAY-CURTIS distance. Groups for the nodal analysis signed by respective letters

The majority of species belonging to the other groups are common to both sites. *Deutonura portucalensis* and *Arrhopalites sericus*, representing group B, are present both in litter of eucalyptus and soil of pine wood, but the first species occurs also in the soil of the exotic stand. Groups C and D, particularly the last one, have high constancy values for almost all the strata and therefore low or negative fidelity for them (Figs 4, 5), although the former group comprises exclusive species for eucalyptus site *(Ceratophysella gibbosa*, *Protaphorura armata*, *Proctostephanus madeirensis* and *Lepidocyrtus lusitanicus*).



4. Constancy values for post-clustering nodal analysis. Collection and species groups according to figs. 2 and 3 respectively

The species of group E show high values of constancy in organic and mineral horizons of pine wood and in soil of eucalyptus stand. Among the species of group G, only *Tetracanthella proxima* is exclusive of pine wood. This group is very constant in organic and mineral strata of pine wood and litter of eucalyptus stand. Its values of fidelity are moderate for the first two strata and low for the third one.



5. Fidelity values for post-clustering nodal analysis. Collection and species groups according to figs 2 and 3 respectively

DISCUSSION

Our comparative study of collembolan populations in a *Pinus pinaster* forest and an *Eucalyptus globulus* plantation did not reveal clear signs of disturbed structure of the populations as a consequence of eucalyptus reafforestation. Nevertheless, a difference is observed specially if we consider data as a whole and not separated into distinct strata.

Similarity data of the two sites (Fig. 1) show that their values are not significantly different, except when we consider all strata grouped together. Also, the fauna of pine wood, although less abundant than that of eucalyptus, is richer and more diverse (Table 2).

In another study, also comparing the fauna from the same tree species (GAMA et al. 1994, VASCONALOS et al. 1994), we found no clear difference between both stands. In opposition to this study, the abundance of animals was higher in *Pinus pinaster* and the richness was higher in eucalyptus stands. This shift may be explained by the higher litter thickness and organic matter content in the pine wood site than in the eucalyptus site, contrary to the situation found in this study.

Therefore, litter quality seems important in explaining collembolan densities. As pointed out by RUSEK (1989) the moisture-holding capacity of litter, dependent on these parameters, has great importance since higher densities and species richness are usually associated with humid environments. In fact, in this study litter thickness and water content in organic horizon have higher values in eucalyptus than in pine wood (Table 1).

In the present case, the Q cluster analysis (Fig. 2) did not reveal a separation between the sites, suggesting that organic horizon of pine wood is more related with the organic and mineral horizons of eucalyptus stand than with the correspondent mineral horizon. Only pitfall traps are clustered together.

The R analysis cluster (Fig. 3) revealed the existence of 10 groups of taxa. The majority of the species of groups B, C, D, E and G constitute 50% of the total and occur in organic and mineral horizons of both sites (Table 2). However, group D also appears in pitfall samples. Therefore, we cannot speak of a clear separation between sites, nor of any distinguished stratification between the two strata.

Nevertheless, most of the other species reveal exclusivity: 12 species of groups A, H and C to eucalyptus and 17 species of groups F, I and J to pine wood, with affinity to litter (groups A and F), soil (H and I), litter and soil (C) or pitfall samples (group J).

Constancy and fidelity data (Figs. 4, 5) also reflect a certain homogeneity between biotopes. Constancy values are very high on the majority of the nodes and fidelity to the strata is generally low, except in some groups revealing exclusivity.

The weak separation between faunas may be related to the habitat resemblance of both stands, resulting from the fact that the eucalyptus plantation is not currently exploited and from the procedures used in the establishment of the plantation, particularly the groove formation. This leads to an enrichment of the system due to a large accumulation of organic debris and to the development of a constant vegetation cover, which provides a suitable microhabitat configuration for *Collembola*.

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